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A comparison for Turkish provinces' performance of urban air pollution

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ABSTRACT

The objective of this paper is to assess the environmental performance of Turkish provinces by using a non-parametric method, Data Envelopment Analysis. The results of ranking are based on the provinces' ability to produce the largest equi-proportional increase in the desirable output-gross domestic product and decrease in the undesirable output namely, air pollutants. The results indicate that 7.41% of the sample provinces are relatively efficient. The results also show that, regions with the highest level gross domestic product per capita have the highest efficiency scores. New industrial districts have lower efficiencies in spite of relatively higher income per capita. In the second stage of the study the possible relationship between environmental efficiency scores and input, output variables are investigated by a regression analysis. According to the results, there is a positive relationship between gross domestic product and efficiency scores.

Contents

1. Introduction

In recent years, Turkey has experienced increasing environmental pressures, on account of rapid industrialization and urbanization. Average annual growth rate of urban population was 2.1% in the period of 2000–2008 and at the end of 2008, 69% of total population lived in urban areas [1]. Three largest metropolitans, namely İstanbul, Ankara and İzmir provinces, are resided by nearly 30% of the country's total population [2]. During the period 1998–2008, average growth rate of gross domestic product (GDP) was 4.7% and at the end of the 2008, Turkey ranked 17th in the world in GDP [3].

Starting with the second half of 1970s, especially in the winter months, urban air pollution has become a significant problem. Studies carried out between 1990 and 1996 estimate that approximately 15 million inhabitants of major Turkish cities are exposed to sulphur dioxide (SO_2) and particulate concentrations above World Health Organization (WHO) guidelines [4]. Major sources of air pollution are the combustion of fossil fuels, lead additives in gasoline and heavy industries. Air pollution is exacerbated by the use of high sulphur fuel oil, old vehicle technology with no emission control equipment and often poorly operated, if any, industrial

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abatement technology. Low-quality coal, and high sulphur content local lignite, petroleum, wood and dried dung consumption in the households and transportation seem to be important factors for high concentrations of particulate matter (PM_{10}) and SO_2 levels [5].

In the 1990s, there has been a decrease in concentrations of SO_2 and PM in urban areas. Most of this improvement can be attributed to fuel substitution (from high sulphur content domestic coal to natural gas) in residential heating and power generation. However, in some urban and industrial centres ambient air pollution still poses a threat to public health since SO_2 and particulates exceeding national air quality standards [6].

Since an increasing percentage of the Turkey's population lives in urban areas, improving air quality is a significant aspect of promoting sustainable human settlements. Given this motivation, several studies on urban air pollution of a single settlement centre in Turkey have been conducted [7–17]. Güneş [18] evaluates the results of the precautions concerning fuels, combustion systems and methods with the help of the SO_2 and PM data of the city centres between 1993 and 2002 during the winter season. The results of his study indicate that the number of city centres that exceeds both winter season and annual limit values has been decreasing regularly.

However, existing literature on the linkages between air pollution and economy are fewer in comparison. Focusing on air quality improvements, Zaim [5] estimates health and economic benefits of reducing PM_{10} and SO_2 levels to the WHO standards in Turkey's major towns in 1990 and 1993. The estimated economic value of avoiding these effects is nearly 0.12% and 0.08% of the 1990 and 1993 gross national product. Similarly, for the 1992–2001 period using SO_2 and total suspended PM levels as air pollution indicators, Özdilek [19] calculated expected monetary gains by reducing health related problems caused by outdoor air pollution in Turkish cities.

Akbostancı et al. [20] investigate the relationship between air pollution and income both national and local levels for 1992–2001 period. At the local level, the study covers 58 Turkish provinces. Employing a panel data model, they find an N shape relationship between emissions of air pollutants (PM_{10} and SO_2) and income.

The purpose of this paper is to address this issue and evaluate the relative environmental efficiency of Turkish provinces in the context of pollution emissions through the models based on Data Envelopment Analysis (DEA). In this paper, 2 inputs and 3 outputs are considered, which reflect the economy and air quality of the provinces. SO_2 and PM_{10} emissions which included as undesirable outputs are local air pollutants. These pollutants affecting both human and ecosystem health, are mainly the results of combustion of fossil fuels and industrial process.

Although SO_2 is emitted naturally by volcanoes, the major anthropogenic source of sulphur emission is energy related. SO_2 is generated in the combustion of coal, high-S fuel oils, and smelting of metallic ores [21]. When sulphur compounds settle out of the atmosphere in the form of wet deposition (acid rain) or dry deposition, the resulting acidification of soils and surface waters can have serious consequences for plant life and water fauna [22]. Besides, acidification can also damage buildings and cultural monuments [23]. In many locations, SO_2 particles in the atmosphere are the largest source of haze and impaired visibility [24].

PM refers to the solid and liquid particles that are dispersed into ambient air. PM is not a specific chemical entity but is a mixture of particles from different sources and of different sizes, compositions, and properties [25]. PM is made up of a number of components, including acids (such as nitrates and sulphates), organic chemicals, metals, soil or dust particles, and allergens (such as fragments of pollen or mould spores) [26]. Larger particles are visible as smoke or dust and settle out relatively rapidly. The tiniest particles can be suspended in the air for long periods of time and are the most harmful to human health [27].

The majority of total PM emissions to the atmosphere are attributable to natural sources, such as suspended terrestrial dust, oceans and seas, volcanoes, forest fires and natural gaseous emissions [28]. However, these emissions are dispersed rather evenly into the atmosphere and, therefore, result in a relatively low tropospheric background PM concentration. The major sources of anthropogenic particles include transportation, stationary combustion, space heating, biomass burning, and industrial and traffic-related fugitive emissions (street dust). The majority of anthropogenic PM is emitted within relatively small urban and industrial areas, resulting in hot spots of high concentrations of PM and other air pollutants.

Similar to SO_2, the deposition of PM can change the nutrient composition of soils and surface waters and affects the diversity of ecosystems [24]. PM is a significant contributor to reduced visibility. Numerous studies have linked SO_2 and particle levels to increased hospital admissions and emergency room visits and even to death from heart or lung diseases. Both long- and short-term particle exposures have adverse health effects such as increased asthma attacks, chronic bronchitis, reduced lung functions and even premature death [24,26]. People with heart or lung diseases, children, and the elderly are particularly vulnerable to those effects.

The rest of the paper is organised as follows. Data envelopment analysis is shortly described in Section 2. Section 3 explains the models and data used in this study. Section 4 presents the main findings and analyses the results. Section 5 summarizes the results and draws the final conclusions.

2. Data envelopment analysis

DEA is a linear programming technique for measuring the relative efficiencies of operating units performing similar functions. Given that efficiency analysis plays a significant role in assessing the performance of decision-making units (DMUs) in relation to the best practice, it is not surprising that DEA has been extensively used in many areas of economics. When demands for better environmental quality have been growing, the accurate assessment of environmental performance is strongly needed. Accordingly, energy and environmental studies using DEA has been intensified in recent years. Zhou et al. [29] provide a detailed literature survey on the application of DEA to energy and environmental studies. In the literature the applications of DEA to estimate environmental performance are mainly focussed on comparing three types of units, namely environmental performance of various countries, of various sectors, firms, farms or plants, and of environmental management systems [30]. Some of the studies concern one environmental pressure type, like nitrogen, energy-related emissions such as carbon dioxide (CO_2), SO_2 and nitrogen oxides (NO_x) or waste. Other studies, however, apply DEA analysis across several pressure (emission) types. This section describes two different models employed in the present analysis.

DEA estimates relative efficiencies of objects in a group, or DMUs, which use inputs to produce outputs. Assume that there are N DMUs, and that the DMUs under consideration convert I inputs to J outputs. In particular, let the mth DMU produce outputs y_{jm} using x_{im} inputs. The objective of the DEA exercise is to identify the DMUs that produce the largest amount of outputs by consuming the least amounts of inputs. A DMU is deemed to be efficient if the ratio of weighted sum of outputs to the weighted sum of inputs is the highest. Hence, the DEA program maximizes the ratio of weighted

outputs to weighted inputs for the DMU under consideration subject to the condition that the similar ratios for all DMUs be less than or equal to one. Thus a model for calculating the efficiency of the mth DMU given as follows [31–33]:

$$\max\left(\frac{\sum_{j=1}^{J} v_{jm}y_{jm}}{\sum_{i=1}^{I} u_{im}x_{im}}\right)$$

subject to

$$0 \le \left(\frac{\sum_{j=1}^{J} v_{jm}y_{jn}}{\sum_{i=1}^{I} u_{im}x_{in}}\right) \le 1; \quad n = 1, 2, \ldots, N \tag{1}$$

$$v_{jm},\ u_{im} \ge \varepsilon; \quad i = 1, 2, \ldots, I; \quad j = 1, 2, \ldots, J$$

where the subscript i stands for inputs, j stands for outputs and n stands for the DMUs. The variables u_{im} and v_{jm} are the weights of inputs and outputs, respectively, to be determined by the above mathematical program. The second subscript m represents the base DMU for which the efficiency is being calculated. The ε is an arbitrarily small positive number introduced to ensure that all of the known input and outputs have positive weight values. The optimal value of the objective function is the DEA efficiency score assigned to the mth DMU. If the efficiency score is 1, the mth DMU satisfies the necessary condition to be DEA efficient and is said to be located on frontier that envelopes all the data; otherwise, it is DEA inefficient. The efficiency is relative to the performance of other DMUs under consideration.

It is difficult to solve the above program because of its fractional objective function. However, if either the denominator or numerator of the ratio is forced to be unity, then the objective function will become linear, and a linear programming problem can be obtained. For example, by setting the denominator of the ratio equal to unity, one can obtain the following *output maximization* linear programming problem. It may be noted that by setting the numerator equal to unity, it is equally possible to produce *input minimization* linear programming problem.

$$\max\left(\sum_{j=1}^{J} v_{jm}y_{jm}\right)$$

subject to

$$\left(\sum_{i=1}^{I} u_{im}x_{in}\right) = 1; \tag{2}$$

$$\left(\sum_{j=1}^{J} v_{jm}y_{jn} - \sum_{i=1}^{I} u_{im}x_{in}\right) \le 0; \quad n = 1, 2, \ldots, N$$

$$v_{jm},\ u_{im} \ge \varepsilon; \quad i = 1, 2, \ldots, I; \quad j = 1, 2, \ldots, J$$

Eq. (2) is called the *output maximizing multiplier version* in the DEA literature [33]. This model is used to compute the efficiency of just the mth DMU. To get the efficiency scores of all other DMUs, N such models should be solved, each for a base DMU ($m = 1, 2, \ldots, N$). In each model, the constraints are the same while the ratio to be maximized is changed.

Computation of efficiency is usually done with the dual of Eq. (2). The dual constructs a piecewise linear approximation to the true frontier by minimising the quantities of the different inputs to meet the stated levels of the different outputs. The dual is given below:

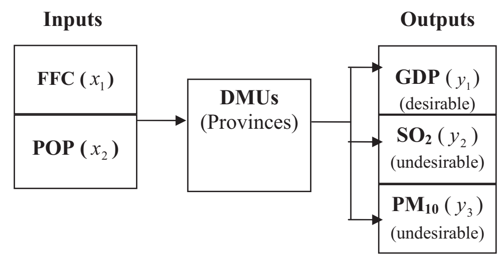


Fig. 1. Input–output indicators of DEA model.

$$\min \theta_m - \varepsilon\left(\sum_{i=1}^{I} s_i - \sum_{j=1}^{J} s_j\right)$$

subject to

$$\sum_{n=1}^{N} y_{jn}\lambda_n - s_j = y_{jm}; \quad j = 1, 2, \ldots, J \tag{3}$$

$$\theta_m x_{im} - \sum_{n=1}^{N} x_{in}\lambda_n - s_i = 0; \quad i = 1, 2, \ldots, I$$

$$\lambda_n, s_j, s_i \ge 0$$

This dual rates a particular DMU (mth DMU here). This DMU is relatively efficient if and only if the optimal values of its efficiency ratio, θ_m, equals unity and the optimal values of all the slack variables s_i and s_j are zero for all i and j. Eq. (3) assumes constant returns to scale (CRS). However, weight vectors, λ_n in variable returns to scale (VRS) can be incorporated in it by appending the constraint:

$$\sum_{n=1}^{N} \lambda_n = 1$$

Scale efficiency of a DMU is equal to one if the DMU is operating at its most productive scale size; otherwise scale efficiency is less than one. Thus, the VRS efficiency of a DMU is always more than or equal to the CRS efficiency [34,35].

The literature on DEA has many more extensions of these simple models, e.g. the duals of these models, incorporation of variable returns to scale, etc. They will not be explained here, and the details and bibliographies can be found elsewhere [36–38].

3. Data and variables

While computing the relative efficiencies for each of the sample provinces, indicators were divided into input and output groups. Input–output indicators of DEA model is presented in Fig. 1. Fossil fuel consumption (FFC) and population (POP) are denoted by (x_1) and (x_2) respectively in Fig. 1 were employed as two inputs. It was chosen aggregate output as measured by real GDP (y_1), expressed in 1987 prices as the only desirable output. In the case of undesirable outputs, it was used annual mean ambient concentrations of SO_2 (y_2) and PM_{10} (y_3) taking into consideration adverse environmental and health effects of these pollutants.

Although there are several air pollutants namely, carbon monoxide, hydrocarbons, sulphur oxides, nitrogen oxides (NO_x), lead and secondary pollutants, air pollution measurements in Turkish provinces are limited with SO_2 and PM_{10}. These pollutants have been monitored in the major towns of the Turkey since 1980 [39]. Thus, the measurements of these pollutants representing air pollutant emissions were used as undesirable outputs.

Table 1
Fossil fuel emission levels (kg/billion kcal).

Pollutant	Natural gas	Oil	Coal
SO_2	1.8	2019.6	4663.8
PM	12.6	151.2	4939.2

Table 2
Descriptive statistics of the variables, 1990.

Variables	Mean	Maximum	Minimum	Standard deviation
FFC (BinTep)	445.73	5039.04	18.52	778.20
POP (person)	890,555	7,195,773	175,797	1,044,391
GDP (million TL in 1987 prices)	1,466,134	17,333,961	85,400	2,557,272
SO_2 ($\mu g/m^3$)	111	260	22	59.63
PM_{10} ($\mu g/m^3$)	66	147	25	28.51

Treating SO_2 and PM_{10} emissions poses special difficulties because they are not the traditional output used in DEA. These emissions are undesirable results of the production process, whose production must be minimized. Several methods have been suggested in the literature to modelling undesirable outputs [40,41]. Since more of undesirable outputs are not preferred, this feature may be incorporated either by entering the reciprocals of these outputs or may be assigned a negative sign. Treatment of negative outputs also poses special difficulties in DEA [42,43]. In this study, the reciprocals of SO_2, ($y_2 = 1/y_2$) and PM_{10} emissions ($y_3 = 1/y_3$) are used as output indicators in the DEA models.

FFC, which has been the basic engine for growth, is also a primary driver of air pollutant emissions. Natural gas, as the cleanest of the fossil fuels, can be used in many ways to help reduce the emissions of pollutants into the atmosphere. Burning natural gas in the place of other fossil fuels emits fewer harmful pollutants like SO_2 and PM_{10}. As seen from Table 1, the emission levels of natural gas are negligible in comparison to coal and oil [44]. For that reason, natural gas consumption was excluded from FFC. In the calculations coal and oil consumption in residential, industrial and, transport sectors are considered.

Air pollution, GDP and population data for sample provinces were drawn from Turkish Statistical Institute [45]. The scope of the study has been restricted by the availability of GDP data. Turkish Statistical Institute which is responsible institution from the statistics on the GDP accounts, supplies GDP by provinces data only for the period 1987–2001. Therefore, the environmental performance of the selected provinces analyzed and compared for 1990 and 2000. Fossil fuel consumption data were obtained from Turkish Statistical Institute and Ministry of Energy and Natural Resources of Turkey [45,46]. An overview of the key characteristics of the data for the years 1990 and 2000 are presented in Tables 2 and 3, respectively, in the form of mean, maximum, minimum and standard deviation values. As seen in Tables 2 and 3, maximum to minimum ratios of the inputs and outputs for all DMUs show large-scale differences. This is an expected result because of the scale differences of the maximum to minimum ratios of the inputs and outputs for all DMUs increases while DMUs sizes are increasing [47,48].

Table 3
Descriptive statistics of the variables, 2000.

Variables	Mean	Maximum	Minimum	Standard deviation
FFC (BinTep)	565.35	5990.70	25.05	938.13
POP (person)	1,074,406	10,018,735	194,326	1,440,364
GDP (Million TL)	2,030,187	26,278,326	115,375	3,854,349
SO_2 ($\mu g/m^3$)	68	185	14	31.44
PM_{10} ($\mu g/m^3$)	49	101	10	21.93

Table 4
Correlation coefficient for input and output variables, 1990.

Variables	FFC	POP	GDP	SO_2	PM_{10}
FFC	1.000				
POP	0.939	1.000			
GDP	0.971	0.976	1.000		
SO_2	0.318	0.356	0.323	1.000	
PM_{10}	0.343	0.392	0.341	0.718	1.000

Table 5
Correlation coefficient for input and output variables, 2000.

Variables	FFC	POP	GDP	SO_2	PM_{10}
FFC	1.000				
POP	0.937	1.000			
GDP	0.967	0.980	1.000		
SO_2	0.430	0.384	0.425	1.000	
PM_{10}	0.437	0.430	0.409	0.645	1.000

In order to discriminate effectively the efficient provinces from inefficient ones, the number of provinces should be several times larger than the sum of the number of input-side indicators and output-side indicators [48]. The study covers 54 Turkish provinces. The number of sample provinces satisfies the thumb rules in the literature and, represents the majority of 81 Turkish provinces. Indeed, the studied sample reflected the situation of Turkish provinces comprehensively as they are scattered across Turkey. It should be stated that there is a marked disparity between the provinces in economic development degrees. GDP per capita (2000) of these provinces ranged from \$824 to \$7,556. Moreover, they can be differentiated as small, medium, large and mega provinces in terms of their population.

To ensure the validity of the DEA model specification, an isotonicity test [49] was conducted. This test involves the calculation of all inter-correlations between inputs and outputs for identifying whether increasing amounts of inputs lead to greater outputs. If the correlation of the selected input and output factors is positive (0–1), the factors are isotonically related and can be included in the analysis. And alternatively, when the correlation between input and output is negative, then the variable should be omitted from DEA analysis. Correlation coefficient for selected input and output factors is positive. The correlation coefficients between the selected input and output variables are presented in Tables 4 and 5 for the years 1990 and 2000, respectively.

In this study, output oriented CRS and output oriented VRS models were used in the calculations. The DEA analysis calculation was performed using the DEAP (Data Envelopment Analysis Program) software package [50] downloadable freely for academic purposes from the Internet.

4. Results

4.1. Computed results

First it was used CRS and VRS models to measure the relative efficiencies. The results given in Table 6 provide efficiency performance indicators of 54 provinces for the year 2000. As seen from Table 6, only five provinces perform efficiently, namely Bingöl, Bolu, Kocaeli, Manisa and Siirt under the CRS assumption. These five provinces have been considered efficient as producing more outputs (more GDP and less ambient concentration of SO_2 and PM_{10}) compared to the remaining 49 provinces considered in the analysis. When VRS is assumed, Ankara, Bilecik, Burdur, İstanbul and Kırşehir have also been considered efficient in addition to the above five provinces. Those with less than one refer to inefficient DMUs. They are not as effective as the other provinces in terms of local

Table 6
Computed results, 2000.

Province	CRS efficiency	VRS efficiency	Scale efficiency	Peers
Adana	0.647	0.720	0.899	Manisa, Bolu
Adıyaman	0.435	0.436	0.998	Bingöl, Manisa, Bolu
Afyon	0.563	0.563	1.000	Manisa, Bolu
Ağrı	0.501	0.507	0.988	Manisa, Bolu, Bingöl
Amasya	0.665	0.665	1.000	Bingöl, Manisa, Bolu
Ankara	0.881	**1.000**	0.881	Bolu, Manisa
Antalya	0.608	0.655	0.927	Bolu, Manisa
Aydın	0.884	0.885	0.998	Manisa, Bolu, Bingöl
Balıkesir	0.598	0.621	0.964	Manisa, Bolu
Bilecik	0.827	**1.000**	0.827	Kocaeli, Bolu
Bingöl	**1.000**	**1.000**	**1.000**	–
Bolu	**1.000**	**1.000**	**1.000**	–
Burdur	0.885	**1.000**	0.885	Bingöl, Manisa, Bolu
Bursa	0.675	0.736	0.916	Bolu, Kocaeli
Çanakkale	0.702	0.720	0.975	Manisa, Bolu
Çorum	0.862	0.867	0.993	Manisa, Bolu
Denizli	0.702	0.730	0.962	Manisa, Bolu
Diyarbakır	0.740	0.741	1.000	Manisa, Bolu
Edirne	0.796	0.909	0.875	Bolu, Bingöl
Elazığ	0.382	0.387	0.988	Bolu, Manisa
Erzurum	0.561	0.563	0.996	Manisa, Bingöl
Eskişehir	0.717	0.725	0.990	Bolu, Manisa
Gaziantep	0.466	0.493	0.946	Manisa, Bolu
Giresun	0.649	0.649	0.999	Manisa, Bolu
Hatay	0.460	0.498	0.923	Bolu, Kocaeli
Isparta	0.477	0.480	0.993	Manisa, Bolu
İçel	0.691	0.725	0.953	Manisa, Bolu
İstanbul	0.854	**1.000**	0.854	Bolu, Manisa
İzmir	0.764	0.881	0.867	Bolu, Kocaeli
Kastamonu	0.697	0.709	0.983	Manisa, Bolu
Kayseri	0.466	0.474	0.983	Bolu, Manisa
Kırklareli	0.787	0.812	0.969	Bolu, Kocaeli
Kırşehir	0.807	**1.000**	0.807	Manisa, Bolu, Bingöl
Kocaeli	**1.000**	**1.000**	**1.000**	–
Konya	0.440	0.500	0.881	Bolu, Manisa
Kütahya	0.617	0.620	0.994	Manisa, Bingöl
Malatya	0.611	0.613	0.997	Bingöl, Manisa, Bolu
Manisa	**1.000**	**1.000**	**1.000**	–
K.Maraş	0.387	0.394	0.980	Manisa, Bolu
Muğla	0.867	0.899	0.965	Manisa, Bolu
Nevşehir	0.759	0.764	0.993	Bolu, Bingöl
Niğde	0.615	0.615	1.000	Bingöl, Manisa, Bolu
Ordu	0.689	0.690	0.999	Manisa, Bolu
Rize	0.747	0.748	0.999	Manisa, Bolu
Samsun	0.715	0.726	0.985	Bingöl, Manisa, Bolu
Siirt	**1.000**	**1.000**	**1.000**	–
Sivas	0.671	0.671	0.999	Manisa, Bolu
Tekirdağ	0.643	0.701	0.917	Kocaeli, Bolu
Tokat	0.948	0.954	0.994	Manisa, Bingöl
Trabzon	0.802	0.803	0.999	Manisa, Bolu
Uşak	0.426	0.450	0.947	Manisa, Bolu
Yozgat	0.783	0.792	0.989	Manisa, Bolu, Bingöl
Zonguldak	0.418	0.421	0.993	Bolu, Kocaeli
Kırıkkale	0.897	0.720	0.999	Bingöl, Manisa, Bolu
Average	**0.700**	**0.730**	**0.962**	

pollutants. Elazığ is rated as the least efficient both under the CRS and VRS assumptions. In 2000, CRS and VRS efficiencies of Elazığ are 0.382 and 0.387, respectively.

As expected, the VRS efficiencies that measure pure technical efficiencies excluding effects of scale of operations are larger than the corresponding CRS efficiencies. For example, the CRS efficiency of Adana is 0.647, and its score increases to 0.720 under the VRS assumption. The CRS efficiency score is lower because this province does not operate at a best possible scale size. The ratio of CRS and VRS efficiency is the scale efficiency. Table 6 provides the details on scale efficiencies of the provinces. For example, the scale efficiency of Adana is 0.899 which is less than one, meaning that the province is not able to register unit efficiency because it is not operating at the most productive scale size, and its present size of operations reduces its pure technical efficiency. Likewise Ankara, Bilecik,

Table 7
Frequency distribution of CRS efficiencies, 2000.

Value	Count	Percent	Cumulative count	Cumulative percent
[0.3, 0.4]	2	3.70	2	3.70
[0.4, 0.5]	8	14.82	10	18.52
[0.5, 0.6]	4	7.41	14	25.93
[0.6, 0.7]	13	24.07	27	50
[0.7, 0.8]	11	20.37	38	70.37
[0.8, 0.9]	10	18.52	48	88.89
[0.9, 1]	1	1.85	49	90.74
[1]	5	9.26	54	100
Total	54	100	54	100

Table 8
54 cities and the computed results, 1990.

Province	CRS efficiency	VRS efficiency	Scale efficiency	Peers
Adana	0.626	**1.000**	0.626	Bolu, Kocaeli
Adıyaman	0.573	0.635	0.902	Bolu, Siirt
Afyon	0.465	0.575	0.809	Bolu, Siirt
Ağrı	0.488	0.527	0.927	Bingöl, Siirt
Amasya	0.518	0.679	0.763	Bilecik, Siirt, Bolu
Ankara	0.699	**1.000**	0.699	Bolu, Siirt
Antalya	0.556	0.886	0.627	Siirt, Kocaeli, Bolu
Aydın	0.641	0.821	0.781	Siirt, Bolu
Balıkesir	0.526	0.764	0.688	Siirt, Bolu
Bilecik	**1.000**	**1.000**	**1.000**	–
Bingöl	**1.000**	**1.000**	**1.000**	–
Bolu	**1.000**	**1.000**	**1.000**	–
Burdur	0.714	0.726	0.983	Bilecik, Siirt, Bolu
Bursa	0.601	0.719	0.836	Kocaeli, Bolu
Çanakkale	0.724	0.917	0.789	Bilecik, Siirt, Bolu
Çorum	0.612	0.716	0.855	Bolu, Siirt
Denizli	0.518	0.708	0.731	Kocaeli, Bolu
Diyarbakır	0.854	**1.000**	0.854	Siirt
Edirne	0.604	0.866	0.698	Siirt, Bolu, Bilecik
Elazığ	0.423	0.479	0.885	Bolu, Kocaeli
Erzurum	0.550	0.630	0.873	Siirt
Eskişehir	0.530	0.752	0.704	Kocaeli, Bilecik, Bolu
Gaziantep	0.482	0.632	0.763	Kocaeli, Bolu
Giresun	0.496	0.648	0.765	Bolu, Siirt
Hatay	0.423	0.566	0.747	Bolu, Kocaeli
Isparta	0.433	0.564	0.767	Bilecik, Siirt, Bolu
İçel	0.663	0.937	0.707	Siirt, Bolu
İstanbul	0.740	**1.000**	0.740	Kocaeli, Bolu
İzmir	0.655	0.891	0.735	Kocaeli, Bolu
Kastamonu	0.490	0.565	0.867	Siirt, Bolu
Kayseri	0.331	0.467	0.709	Kocaeli, Bolu
Kırklareli	0.862	0.882	0.977	Kocaeli, Bilecik, Bolu
Kırşehir	0.576	0.591	0.975	Bilecik, Siirt, Bolu
Kocaeli	1.000	1.000	1.000	–
Konya	0.372	0.517	0.720	Kocaeli, Bolu
Kütahya	0.540	0.621	0.869	Bolu, Siirt
Malatya	0.516	0.616	0.838	Bolu, Siirt
Manisa	0.801	1.000	0.801	Bolu, Siirt
K.Maraş	0.378	0.516	0.732	Siirt, Bolu
Muğla	0.705	0.973	0.724	Bilecik, Siirt, Bolu
Nevşehir	0.622	0.655	0.949	Bilecik, Siirt, Bolu
Niğde	0.679	0.803	0.846	Siirt, Bolu, Bilecik
Ordu	0.510	1.000	0.510	Siirt
Rize	0.640	0.768	0.833	Siirt, Kocaeli, Bolu
Samsun	0.696	0.888	0.784	Bolu, Siirt
Siirt	**1.000**	**1.000**	**1.000**	–
Sivas	0.490	0.571	0.858	Bolu, Siirt
Tekirdağ	0.594	0.628	0.946	Kocaeli, Siirt, Bilecik
Tokat	0.663	0.751	0.883	Siirt
Trabzon	0.681	0.927	0.735	Siirt
Uşak	0.484	0.504	0.960	Bolu, Bilecik, Siirt
Yozgat	0.448	0.624	0.718	Siirt
Zonguldak	0.550	0.592	0.929	Bolu, Siirt, Kocaeli
Kırıkkale	0.565	0.601	0.941	Bolu, Siirt
Average	**0.617**	**0.754**	**0.821**	

Table 9
GDP per capita and the CRS efficiencies of NUTS 1 regions.

Region	GDP per capita (in US dollars)	Rank	Region	CRS score	Rank
Aegean	2952	5	Aegean	0.728	3
Central Anatolia	2179	8	Central Anatolia	0.714	6
Centraleast Anatolia	1727	10	Centraleast Anatolia	0.664	8
East Black Sea	1904	9	East Black Sea	0.722	4
East Marmara	4725	1	East Marmara	0.844	2
İstanbul	4416	2	İstanbul	0.854	1
Mediterranean	2673	6	Mediterranean	0.594	11
Northeast Anatolia	1138	12	Northeast Anatolia	0.531	12
Southeast Anatolia	1611	11	Southeast Anatolia	0.660	10
West Anatolia	3195	4	West Anatolia	0.661	9
West Black Sea	2435	7	West Black Sea	0.718	5
West Marmara	3536	3	West Marmara	0.705	7

Burdur, İstanbul and Kırşehir are not operating at the best possible scale size considering their VRS and CRS scores. In other words, these provinces are locally efficient but not nationwide efficient due to their scale size.

Table 6 also gives information about peers for provinces considered inefficient in the analysis. For example, Adana's peer is both Manisa and Bolu meaning that Adana can try to emulate Manisa and Bolu in order to register the values of indicators that will enable it to be considered best in the DEA study.

The estimated CRS efficiencies for the year 2000 are summarized in Table 7. It should be noted that nearly 30% of provinces has remarkably high CRS scores, ranging from 0.8 to 1 while the majority of the sample provinces have intermediate values.

The performances of the provinces in an earlier year, namely 1990 are presented in Table 8. There are some interesting changes in the efficiencies of 54 provinces in 1990 compared to 2000 (shown in Table 6). As a whole, the environmental performance of Turkish provinces had been improved from 1990 to 2000, in CRS model.

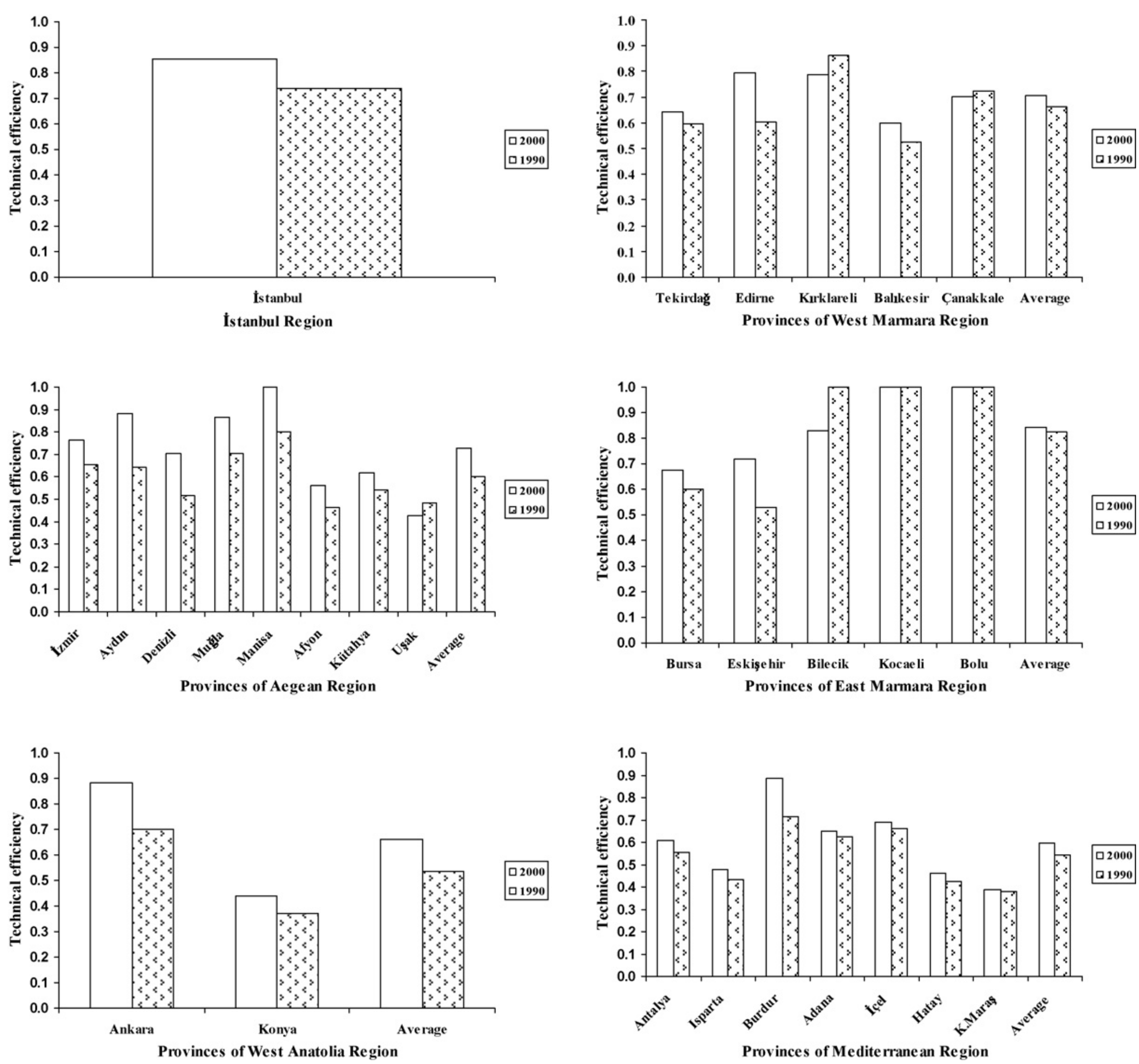


Fig. 2. Technical efficiencies according to the regional disparities of Turkey.

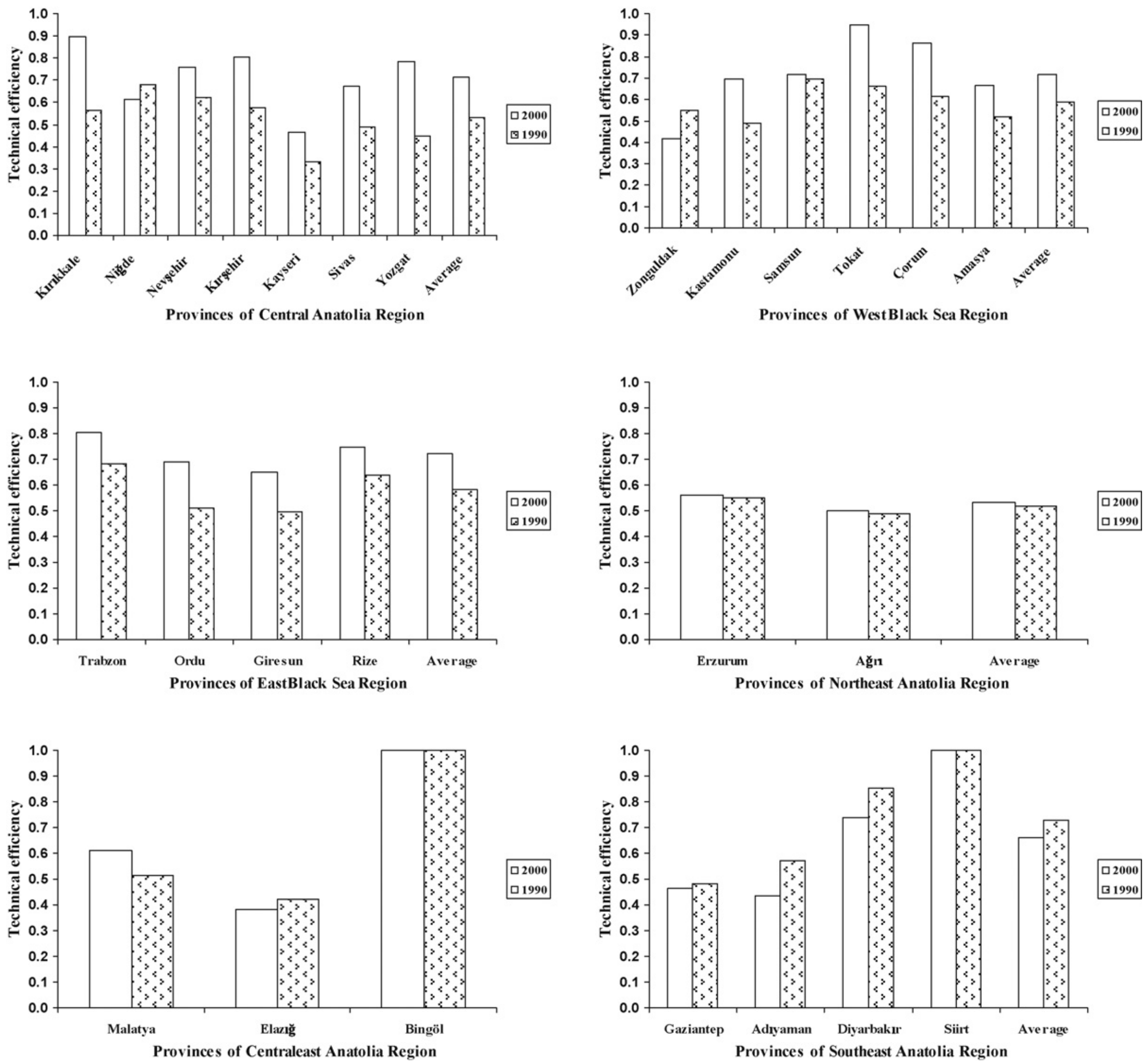


Fig. 2. (*continued*)

The average CRS efficiency increased from 0.617 to 0.700. On the other hand, the overall performance deteriorated on the basis of computed VRS efficiencies. The average VRS efficiency score in 1990 (0.754) was higher than that (0.730) in 2000. It is noteworthy that remarkably industrialized three largest metropolitans, namely Ankara, İstanbul and İzmir provinces showed improved performance with higher CRS scores, although they are not fully efficient in 2000.

Bingöl, Bolu, Kocaeli and Siirt are efficient under CRS assumption both in 1990 and 2000. (Bilecik is efficient in 1990 but not efficient in 2000. Manisa is efficient in 2000 but not efficient in 1990.) When VRS is assumed, Adana, Ankara, Bilecik, Bingöl, Bolu, Diyarbakır, İstanbul, Kocaeli, Manisa, Ordu and Siirt are also considered efficient in 1990. Kayseri is the worst performer both under the CRS and VRS assumptions. In 1990, CRS and VRS efficiencies of Kayseri are 0.331 and 0.467, respectively.

Although the results show considerable variation in relative rankings of provinces with respect to VRS efficiency across the years, Ankara, Bilecik, Bingöl, Bolu, İstanbul, Kocaeli Manisa and Siirt have kept their position within the best performers. Elazığ, Hatay, Isparta, Kayseri, Konya, Kahramanmaraş and Uşak on the other hand, were persistently ranked within the 10 provinces with least VRS scores. In 2000 Adana, Diyarbakır and Ordu exhibited a decline while Burdur and Kırşehir recorded a progress in environmental performance.

4.2. Regional disparities of CRS efficiencies

In order to development and harmonization of EU regional statistics and for socio-economic analyses of the regions in 2002 Nomenclature of Territorial Units for Statistics (NUTS) was established. At NUTS 1 level, all provinces have been aggregated into 12 territorial units according to the sizes of population by regarding economic, social, cultural, geographical factors [45]. The only exception to this is İstanbul as the province of İstanbul is a region by itself in terms of NUTS 1.

Turkey is a moderately large country with varying geographic, economic, social, etc. characteristics. The population and industrial activities are concentrated at the western part and the shoreline areas of the country. The economic growth performance of Turkey has not eliminated developmental disparities between regions and there is a wide developmental disparity between The Western and the Eastern regions. 3 of the 5 efficient provinces, namely Bolu, Kocaeli and Manisa are found in the West.

Fig. 2 shows the disparity in CRS efficiency among NUTS 1 regions for the years 2000 and 1990. Comparison of relative

Table 10
Output targets to get efficient cities for the year 2000.

Province	Real values			Calculated values		
	GDP (million TL)	SO_2 (μg/m^3)	PM_{10} (μg/m^3)	GDP (million TL)	SO_2 (μg/m^3)	PM_{10} (μg/m^3)
Adana	3,565,131	33	25	5,507,729	3	2
Adıyaman	491,854	119	71	1,131,012	43	31
Afyon	829,715	71	67	1,474,213	40	31
Ağrı	183,939	81	50	367,070	38	25
Amasya	419,322	75	40	630,576	37	26
Ankara	9,545,749	47	57	10,840,304	4	3
Antalya	2,938,699	49	71	4,836,960	5	4
Aydın	1,807,663	47	28	2,045,710	32	25
Balıkesir	1,789,308	69	33	2,990,581	10	7
Bilecik	573,390	37	25	693,589	29	21
Bingöl	**115,375**	**89**	**57**	**115,375**	**89**	**57**
Bolu	**859,666**	**14**	**10**	**859,666**	**14**	**10**
Burdur	415,958	74	54	469,818	67	48
Bursa	5,015,684	62	47	7,433,954	2	2
Çanakkale	1,017,588	95	19	1,448,622	9	6
Çorum	871,556	96	86	1,011,490	83	67
Denizli	1,817,721	105	75	2,588,917	6	4
Diyarbakır	1,196,370	85	86	1,615,793	63	53
Edirne	756,830	52	11	965,934	12	9
Elazığ	630,710	52	39	1,649,591	12	9
Erzurum	577,505	150	61	1,029,970	50	34
Eskişehir	1,424,621	43	47	1,986,879	13	10
Gaziantep	1,741,987	92	55	3,739,145	5	4
Giresun	475,173	45	36	732,363	29	21
Hatay	1,888,771	53	51	4,107,309	3	2
Isparta	570,308	65	77	1,195,647	31	23
İçel	3,079,797	74	68	4,460,127	10	8
İstanbul	26,278,326	51	53	30,765,410	0	0
İzmir	9,016,134	48	49	11,794,050	2	1
Kastamonu	508,543	54	62	729,105	37	28
Kayseri	1,373,965	77	79	2,949,748	10	7
Kırklareli	921,207	34	33	1,171,081	17	12
Kırşehir	276,285	76	39	342,282	45	31
Kocaeli	**5,223,778**	**51**	**54**	**5,223,778**	**51**	**54**
Konya	2,639,553	43	52	5,995,375	6	5
Kütahya	863,686	185	101	1,400,213	77	63
Malatya	942,046	52	33	1,541,363	28	20
Manisa	**3,273,149**	**56**	**57**	**3,273,149**	**56**	**56**
K,Maraş	1,090,924	95	69	2,821,470	9	7
Muğla	1,896,362	113	38	2,186,184	7	5
Nevşehir	531,770	34	15	743,183	16	11
Niğde	466,999	91	25	759,595	22	15
Ordu	765,811	49	55	1,110,983	33	25
Rize	469,198	37	61	628,125	28	20
Samsun	1,726,504	36	27	2,415,692	26	19
Siirt	**202,072**	**21**	**26**	**202,072**	**21**	**26**
Sivas	737,199	73	84	1,098,979	50	37
Tekirdağ	1,574,939	43	18	2,450,228	16	12
Tokat	809,183	51	32	853,526	45	30
Trabzon	927,767	48	46	1,156,289	38	29
Uşak	399,655	105	42	939,177	20	15
Yozgat	506,025	100	17	645,871	20	13
Zonguldak	989,486	71	83	2,366,766	14	10
Kırıkkale	619,138	87	25	690,516	31	2

position of regions reveals some interesting results. One particularly interesting result is that, there is no considerable change in the spread between the best and worst performer in time. As seen from Fig. 2, İstanbul and East Marmara Regions have the highest average efficiency scores among the 12 regions, while Northeast Anatolia has the worst. One also notes that, the efficiency scores of these regions present a similar pattern of their economic development even though, the relative rankings of the other regions vary with respect to CRS efficiency and economic development level (see Table 9).

East Marmara and İstanbul regions with the highest GDP per capita also have the highest efficiency scores. Bolu and Kocaeli which rated fully efficient under CRS assumption are found in East Marmara, and this area is the first development axis of İstanbul-centred industry. The economic activities in both regions are dominated by modern industry and service sectors. For the above reason these regions perform well in decoupling of SO_2 and PM_{10} emissions from economic development. On the contrary, Northeast Anatolia is the least efficient and the least developed region.

The efficiency ranking of West Marmara and West Anatolia are not in conformity with their economic development rank. In spite of their relatively higher GDP per capita, these regions have lower efficiencies. Some provinces of these regions for example, Çanakkale, Konya and Tekirdağ with an intensive industrialization dynamics which, in recent years, have been referred to as New Industrial Districts, industry has continued to expand. In fact, West Marmara and West Anatolia have not yet achieved

Table 11
Output targets to get efficient cities for the year 1990.

Province	Real values			Calculated values		
	GDP (million TL)	SO_2 (μg/m^3)	PM_{10} (μg/m^3)	GDP (million TL)	SO_2 (μg/m^3)	PM_{10} (μg/m^3)
Adana	3,016,540	22	42	4,816,442	13	11
Adıyaman	526,741	96	84	919,512	15	16
Afyon	620,310	65	70	1,333,537	11	11
Ağrı	126,976	68	55	294,640	33	27
Amasya	326,300	67	42	629,545	22	22
Ankara	6,579,837	170	103	9,419,472	5	5
Antalya	1,902,320	29	57	3,423,234	16	14
Aydın	1,311,294	50	52	2,044,656	14	14
Balıkesir	1,452,161	71	45	2,763,345	16	14
Bilecik	**377,583**	**76**	**31**	**377,583**	**76**	**31**
Bingöl	**85,400**	**109**	**58**	**85,400**	**109**	**58**
Bolu	**767,034**	**63**	**57**	**767,034**	**63**	**57**
Burdur	297,976	76	41	417,161	29	29
Bursa	3,322,877	190	90	5,524,829	20	17
Çanakkale	798,999	201	33	1,103,948	30	24
Çorum	633,346	146	61	1,034,813	12	13
Denizli	1,159,241	100	54	2,237,900	23	21
Diyarbakır	1,118,803	251	147	1,310,617	8	8
Edirne	498,877	93	33	825,614	23	20
Elazığ	653,023	164	123	1,541,968	40	36
Erzurum	514,740	145	87	936,436	11	11
Eskişehir	991,376	172	43	1,872,095	26	23
Gaziantep	1,504,936	115	69	3,120,794	19	17
Giresun	364,661	46	45	735,359	14	14
Hatay	1,429,209	82	80	3,378,600	17	15
Isparta	437,354	79	52	1,010,057	24	23
İçel	2,348,656	44	41	3,543,726	12	11
İstanbul	17,333,961	241	118	23,437,179	3	3
İzmir	6,338,207	96	77	9,673,453	15	12
Kastamonu	395,629	103	55	808,113	20	20
Kayseri	926,315	161	79	2,797,796	18	16
Kırklareli	790,880	106	47	917,411	63	40
Kırşehir	242,766	99	51	421,356	29	29
Kocaeli	**3,643,984**	**194**	**106**	**3,643,984**	**194**	**106**
Konya	1,957,269	216	95	5,261,422	10	9
Kütahya	671,259	155	81	1,243,887	16	16
Malatya	707,042	135	74	1,370,851	12	12
Manisa	2,247,267	65	46	2,804,617	10	9
K,Maraş	910,575	133	71	2,409,949	15	14
Muğla	1,114,967	69	31	1,582,548	29	22
Nevşehir	428,840	120	57	689,806	38	36
Niğde	356,832	99	36	525,557	26	24
Ordu	566,968	29	25	1,111,311	9	9
Rize	411,768	36	59	643,731	23	23
Samsun	1,426,481	132	55	2,049,018	7	7
Siirt	**356,718**	**28**	**29**	**356,718**	**28**	**29**
Sivas	556,429	260	144	1,135,159	9	9
Tekirdağ	893,035	82	60	1,504,221	48	36
Tokat	564,579	156	113	851,335	12	12
Trabzon	781,090	33	58	1,146,974	9	9
Uşak	308,507	104	63	637,607	34	30
Yozgat	366,837	130	46	819,279	12	13
Zonguldak	1,220,487	75	97	2,220,235	42	38
Kırıkkale	485,990	164	79	859,735	32	31

in balancing their economic development and air pollutant emissions.

4.3. Efficiency optimization

Tables 10 and 11 provides the increased GDP and decreased SO_2 and PM_{10} values that would make inefficient provinces to be deemed efficient by the CCR model for the year 2000 and 1990, respectively.

For example, if Bilecik is to be considered efficient in 2000 keeping the input values are constant; output value of the GDP must be increased from 573,390 million TL to 693,589 million TL, while output values of SO_2 and PM_{10} must be decreased from 37 μg/m^3 and 25 μg/m^3 to 29 μg/m^3 and 21 μg/m^3, respectively (see Table 10).

Similarly, if Manisa is to be considered efficient in 1990, output value of the GDP must be increased from 2,247,267 million TL to 2,804,617 million TL, while output values of SO_2 and PM_{10} must be decreased from 65 μg/m^3 and 46 μg/m^3 to 10 μg/m^3 and 9 μg/m^3, respectively (see Table 11).

5. Relationships between efficiency scores and input/output factors

The DEA results provide the opportunity for the investigation of relationships between provinces scale efficiency values and input and output factors investigated. Only scale efficiency values of the provinces are investigated. Since scale efficiency is based on CRS and VRS efficiencies. In this study, the regression analyses obtained

Table 12
Regression analyses of scale efficiency for the years 1990 and 2000.

Variable	1990 coefficients	2000 coefficients
CONSTANT	1.085 (0.0000)[a]	0.999 (0.0000)[a]
FFC	−6.338E−05 (0.2991)[a]	−4.177E−05 (0.5302)[a]
POP	−3.326E−07 (0.0000)[a]	−2.932E−07 (0.0000)[a]
GDP	1.346E−07 (0.0000)[a]	1.161E−07 (0.0009)[a]
SO_2	−2.386 (0.0921)[a]	−4.615 (0.0010)[a]
PM_{10}	−5.890 (0.0024)[a]	−0.332 (0.6294)[a]
R^2	0.5749	0.4860

[a] All of the coefficients are significant at 99% level.

are based on the "least squares" methodology and EViews 5.0 package [51] is used for the computation of the related parameters. The adopted regression analysis coefficients and R^2 values for the years 1990 and 2000 respectively are given in Table 12. As seen from Table 12, FFC, POP, SO_2 and PM_{10} are negative effect on scale efficiency while GDP is positive effects on scale efficiency.

Although R^2 values of the regression analyses of scale efficiency for the years 1990 and 2000 are not much strong. The sign of the input/output variables in the regression analyses of scale efficiency explain the relationships between scale efficiency and input/output variables. Thus it can be said that reducing (FFC, POP, SO_2 and PM_{10} variables) and increasing (GDP variable) will favourably affect scale efficiency realisations.

6. Policy implications

As a result of this study, several policies might be suggested to increase efficiency scores of Turkish provinces.

(1) Turkey should continue to promote the use of cleaner fuels for motor vehicles and for residential use. In this context, the large potential of renewables should be effectively utilised. The promotion of renewable energy investments should be continued.
(2) Energy saving should be incitement by government and energy saving projects like building integrated solar photovoltaic system, day-lighting, ecological insulation materials, natural/hybrid ventilation, passive cooling, passive solar heating, solar heating of domestic hot water, utilisation of rainwater for flushing should be supported and funded by government.
(3) The people should be motivated towards awareness of environmental issues, rational use of energy in order to increases environmental efficiencies of provinces.
(4) The people should be educated on usage of buildings, which have followed the standards of energy savings. In addition, people should be motivated by government and municipalities to buy those buildings.
(5) Transport policy should be shifted from road to public transport (e.g. railways).
(6) Existing taxes should be revised to support air pollution reduction objectives.
(7) The lack of reliable data hinders to shift environmental management onto more analytically rigorous underpinnings. Therefore investment at the local and national scales in a more complete set of key indicators should be seen as a fundamental policy priority.

7. Summary and conclusions

Many aspects of environmental sustainability can be measured on a relative basis with results that provide a context for policy evaluations and judgments. By the capacity of assembling several economic, social and environmental indicators the DEA provides a foundation for environmental analysis and decision-making. Besides, policy makers benchmark the results of DEA against a relevant peer group which can help to highlight superior environmental programs, strategies, and approaches. In this study, the relative environmental efficiency in air pollutant emissions of Turkish provinces is analyzed and compared through DEA by using real data of 54 provinces. Our DEA models investigates the efficiency performances by taking into account SO_2 and PM_{10} concentrations as the undesirable output of fossil energy consumption along with the desirable output, GDP.

The analysis has shown that 4 of the 54 provinces, namely Bingöl, Bolu, Kocaeli and Siirt have been considered efficient in the years 2000 and 1990. On the other hand Manisa has considered efficient in 2000 and Bilecik has considered efficient in 1990. Elazığ and Kayseri rated as the least efficient in 2000 and 1990, respectively. Ankara, Bilecik, İstanbul, Kırşehir, Manisa and Adana, Ankara, Diyarbakır, İstanbul, Manisa, Ordu are also considered efficient in 2000 and 1990 respectively when variable returns to scale assumption is introduced.

According to the province-level results, changes in the relative efficiency have been minor for most provinces during the sample period. Our results suggest that the first and second tier developed provinces achieve generally high levels of efficiency while New Industrial Districts are generally at low efficiency levels. In terms of regional disparity, the Western regions of Turkey have higher efficiencies.

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